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AIRCRAFT PROGRAM FOR TARGET, BACKGROUND, AND SKY RADIANCE MEASUREMENTS

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Aircraft-based measurement, data reduction and instrument construction work performed for the Air Force Geophysics Laboratory in support of AFGL-and DARPA-sponsored targets characterization and DNA-sponsored nuclear effects simulation programs in the period April 1977 - April 1980 is described and documented.

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FOREWORD

This report summarizes PhotoMetrics' contributions over a period of three years to a joint Air Force Geophysics Laboratory and Defense Advanced Research Projects Agency-sponsored target and backgrounds characterization program directed by the OPR Branch of AFGL, and reviews PhotoMetrics' aircraft-borne measurements of optical auroral emissions in connection with Defense Nuclear Agency's High Altitude Nuclear Effects program. All field measurements were taken from AFGL/OPR's Optical/IR Flying Laboratory, NKC-135A S/N 55-3120. Reference is made to annual Scientific Reports 2 and 1 on this program,[1,2] which present more detailed information on those projects completed between April 1977 and April 1979; and to DNA reports[4,5] in which we presented and interpreted results from the auroral-latitude missions. The report describes engineering modifications to conventional-photographic and video cameras; construction and later upgrading of a low light level video system for auroral monitoring applications; design and construction of an optical bench for precision coalignment of the narrow fields of aircraft-mounted radiometers; and reduction by photogrammetry of ranging and aspect data on targets.

PhotoMetrics' work was directed by R.B. Sluder and I.L. Kofsky, with the field measurements performed by Sluder and D.P. Villanucci. The system for aligning instrument fields was designed by W.S. Andrus, with assistance in mechanical engineering from J.J. Costa. Manuscripts were prepared by Mrs. C.C. Rice. The authors express their thanks to B.P. Sandford, T.P. Markham, E.R. Huppi, R.E. Pierce, A.T. Stair, Jr., and their associates in AFGL's OPR (Optical Physics) Branch for their continued support and encouragement.

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EXECUTIVE SUMMARY

Field measurement and data-evaluation work in support of the Air Force Geophysics Laboratory's programs for determining infrared spectral and spatial signatures of targets and backgrounds is reported. PhotoMetrics maintained and operated boresighting and photogrammetric cameras onboard USAF NKC-135A aircraft S/N 55-3120, which served as the platform for the measurements; tracked the aircraft's spectrometric instruments onto targets; reduced the camera data to determine range and aspect angles of these targets so that absolute directional infrared yields could be measured; and provided scientific crewmembers in missions in which the infrared sky backgrounds resulting from deposition of charged-particle energy in the upper atmosphere were measured. In addition we constructed, modified, and provided engineering services in installation of photographic and photoelectronic cameras, and designed an optical system for coaligning aircraft instruments having very narrow fields of view.

The technical staff participated in a total of 135 measurement flights in 24 separate mission series over the three year contract period. Some 1900 photographic frames of targets of various types were analyzed to compute target ranges and aspects. Since the targets are in general anisotropically-radiating bodies that underfill the fields of view of the aircraft's infrared spectrometers, and some of the radiation is absorbed over the intervening atmospheric path, range and aspect information is needed to determine source intensities (that is, to calibrate the infrared irradiance data). The photogrammetric ranging procedure solves the space resection problem iteratively by comparing the angle subtended by the target from a trial measurement-aircraft position with that recorded on the camera film, and then adjusting the aircraft's position until the two angles agree. Twenty-eight of the aircraft flights were made for the

purpose of measuring the intensity of infrared radiation excited in natural or artificial auroras; in these PhotoMetrics operated low light level video and photographic cameras and a multi-channel visible light-sensitive photometer to characterize the particle energy-input fields.

Extensive modifications were made to existing camera systems on the aircraft, principally for the purpose of permitting viewing of targets in directions other than toward the starboard side of the platform. A low light level video system for determining quantitatively spatial distributions of auroral-particle energy input was designed, constructed, installed in the aircraft, and tested. Its detector is an Intensified Silicon Intensifier Target vidicon; short- and long-focus lenses provide both wide and narrow (high spatial resolution) fields of view; and a four-position filter wheel isolates emission features of interest. The camera system performed to initial design specifications, and took high-quality data on both auroral air fluorescence and a persisting airglow that resulted from release of rocket exhaust molecules in the F-region. The aligner, whose major components are a "Hexcel" rigid optical bench and a 9-cm aperture autocollimator, successfully aligned the optic axes of the aircraft's narrow (0.4°) field auroral radiometer and photometer, and located these instrument fields in the video camera's field of view; this alignment is necessary to ensure that the energy input- and infrared output-measuring instruments are viewing the same volume of excited upper-atmospheric air.

The targets-ranging and camera-modification work was sponsored by the Defense Advanced Research Projects Agency and the Air Force Geophysics Laboratory. The measurements of infrared emission from auroral particle-bombarded air and the construction of the low light level video camera and instrument alignment system were sponsored by the Defense Nuclear Agency.

SECTION I

AIRCRAFT MEASUREMENTS PROGRAM

INTRODUCTION

This work described in this report, which was done under the direction of personnel of the Optical Physics Branch (OPR) of the Air Force Geophysics Laboratory (AFGL), is part of programs to determine spectral and spatial signatures of radiating sources of potential DoD interest and to simulate the infrared sky background emissions that result from upper-atmospheric nuclear explosions. Tasks included preparations for and performance of optical/IR data-taking from USAF aircraft NKC-135A, S/N 55-3120; reduction of photographic target-ranging and -aspect data; and construction and modification of instruments and support equipment for use in the aircraft measurements. We present here a summary of program tasks and responsibilities, a synopsis of the data flights, and a review of two instrument systems that were developed during the three-year contract period.

Detailed descriptions of the tasks performed in the first two years are presented in annual reports [1,2]. The procedure for reducing photogrammetric data on target locations was developed in connection with earlier work [3] in characterizing target signatures by aircraft-borne spectroradiometry. The resulting ranges and aspects have been communicated directly to AFGL/OPR staff for application in their reduction and analysis of spectral and spatial infrared irradiance data. Infrared emissions excited by energetic auroral particles represent the principal direct simulation of the excitation by charged particles and hard radiations from atmospheric nuclear explosions; the data from flights at auroral latitudes in which infrared output and energy input were measured have been successfully reduced and analyzed by PhotoMetrics, under Defense Nuclear Agency sponsorship[4, 5].

FLIGHT PROGRAM

PhotoMetrics' staff participated in a total of 135 measurement flights in 24 separate field trips. Ten of these deployments, comprising 43 individual missions, took place in the last reporting period. Deployments are typically one and two week field trips to one or more air bases in the continental United States and Alaska. Duration of a typical data flight was 5 hours in the infrared signatures program, and about 7 hours for the auroral measurements. In some of the missions two PhotoMetrics staff members served as part of the technical flight crew. Both crew-members maintained their flight qualification throughout the three year work period, taking part in the required USAF training in egress from disabled aircraft, life support procedures, and survival in isolated areas. Their principal in-flight functions were maintaining and operating video and photographic camera systems and photometers, and in addition they tracked infrared spectrometers and imaging devices on targets. This field work constituted a major fraction of the program effort.

Most of the flight missions were designed to obtain infrared spectral irradiance and spatial radiance distributions of targets, and of the sky and earth backgrounds against which targets would be discriminated by surveillance sensors. These data flights were sponsored jointly by the Defense Advanced

Research Projects Agency and the Air Force Geophysics Laboratory. The remaining missions, in which the spectroradiometers pointed toward or near the zenith rather than toward the side, rear, or in the nadir of the aircraft (that is, in the direction of targets), were intended to sense auroral (or in three cases artificial-auroral) emissions. These flights were sponsored by the Defense Nuclear Agency.

TARGET AND BACKGROUND MISSIONS

The measurements of infrared target signatures were made with interferometric spectrometers and thermal imaging scanners designed and constructed by AFGL[6]. The infrared radiations under investigation are in general emitted anisotropically by the sources, and thus the absolute spectral distributions vary as the observer's elevation and azimuth angles are changed. In addition, these emissions are partially absorbed by the intervening atmosphere, and the fields of view of the spectrometers are usually underfilled by the radiating bodies. Therefore the instrument-to-target range as well as the target aspect must be known to permit determination of radiant intensity distributions at the source, which is the quantity of interest in the measurement program.

In these measurement flights PhotoMetrics had responsibility for the photogrammetric and boresighting cameras (Aircraft system E-14) and the video system used to locate and position targets (E-209).

PhotoMetrics was responsible for measuring by photogrammetry the relative positions and orientations in space of the target objects and airborne infrared instruments. The procedure[7] we applied solves this space resection and orientation problem iteratively by comparing the angle subtended by the target from a trial aircraft position with that recorded on the data film, and then adjusting the aircraft position until the two sets of angles agree. Given the parameters of target geometry, dimensions of the target image and calibrated lens focal length, the problem is to locate in space the camera position that will produce the recorded image. The target dimensions were taken from USAF and other data sources, and the image dimensions were measured from the original color and black-and-white film records with the aid of a calibrated microfilm projector.

The specific procedure is as follows (refer to Figure 1). The face angles Θ_1, Θ_2, and Θ_3 are equal in image and object space, the camera lens being the perspective center. These angles are invariant with respect to tilt of either image or target plane, and of choice of coordinate system. The cosines of Θ_i for the image are first computed trigonometrically from the measured positions of images a, b, c of target points A, B, C, taking into account the print focal length (which is the product of lens focal length and print or projection magnification). Then the cos Θ_i are calculated for the target from a trial camera location in space, and compared to the results for the image side of the lens. The position of the camera station is then adjusted and the above calculations repeated until the cosines for the target are equal to those computed for the image. Adjustments to the camera station – determined by solving three simultaneous equations formed by partial differentiation of the expressions for cos Θ_i with respect to x, y and z – are continued until successive changes are less than ~1 meter. If the initial position is not greatly in error, only three or four iterations are required to reach the solution.

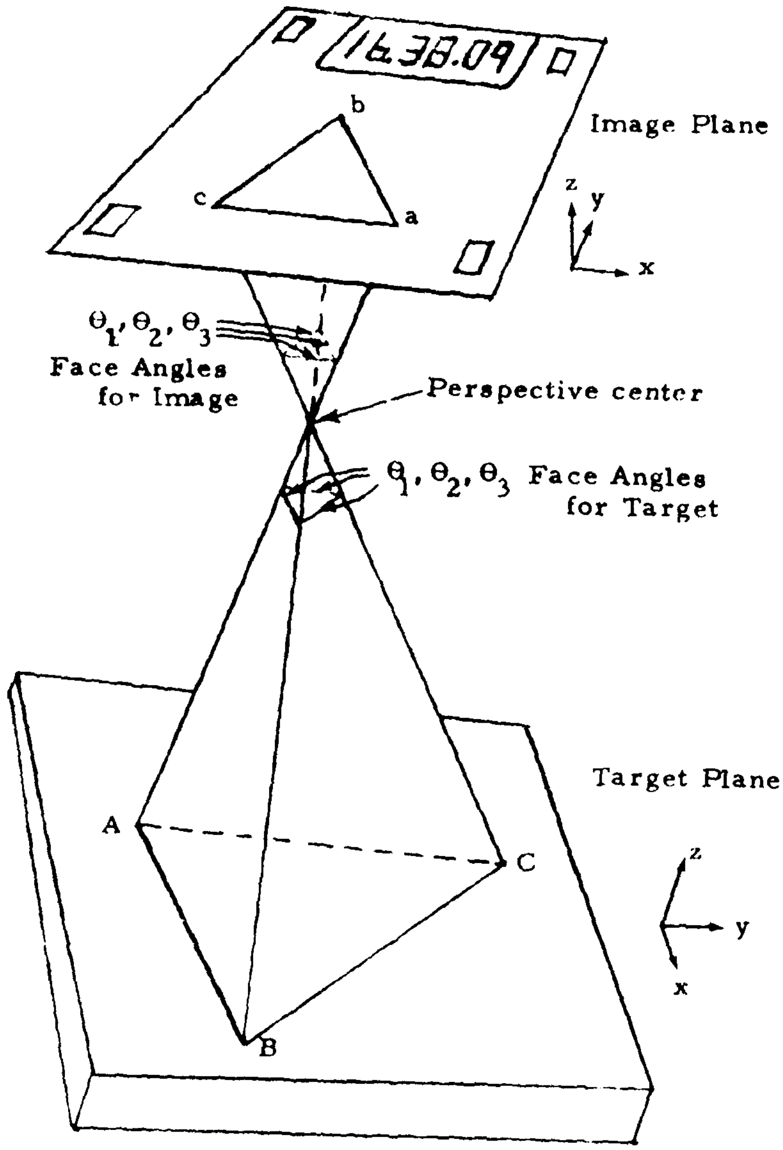

Figure 1. Principle of procedure used to determine camera location relative to target. Face angles θ_i of image and target pyramids are equal and invariant with tilt of either plane.

As noted, this procedure and its implementation in FORTRAN for AFGL's central digital computer were developed for application to this problem in an earlier program.[3] The reduced data on target slant ranges and aspects in flight – from a total of 1900 photographic frames – were turned over directly to OPR during the course of the program, for use in OPR's calibration and interpretation of the spectrum and imaging data from the aircraft missions.

AURORAL MISSIONS

Twenty-five of the 135 flights were auroral missions at high northern latitudes,[4,5] deployed from either Pease AFB, New Hampshire across the auroral oval in eastern Canada, or from Eielson AFB, Alaska which lies within the Q = 3 oval near local midnight.[5] In addition, three flights were made to measure short-wavelength infrared emission from the atmosphere excited by ~3 keV electrons from an EXCEDE rocketborne accelerator[8] in October 1979; and one successfully measured[4,9] the artificial airglows that resulted from release of H_2 and H_2O molecules in the F-region by an Atlas-Centaur satellite launching rocket on 20 Sep 79. Target data on the EXCEDE launch vehicle were also taken.

PhotoMetrics participated in flight planning and in the preparation of Test Plans for aircraft operations in the field. The data missions were flown principally along geomagnetic north-south lines through the auroral oval, so that aircraft instruments could maintain pointing up field lines. For these flights PhotoMetrics' principal function was to take data that provide quantitative information about the spatial and temporal brightness distributions of the visible auroral emissions that indicate energy input into the upper atmosphere. For this purpose, PhotoMetrics calibrated and operated the low-light-level video camera (E-209), the 12-channel photoelectric photometer[3] (E-05), and photographic all-sky cameras (E-13). PhotoMetrics also adjusted and monitored the coalignment of narrow (0.4° square) field-of-view radiometers and photometer, and the video camera in connection with the field operations. The optical bench for accomplishing alignment and the dual-lens low-light-level video system are described in Section II.

SECTION II

INSTRUMENT DEVELOPMENT

AURORAL LOW LIGHT LEVEL VIDEO SYSTEM

A high-sensitivity recording video system was specified, designed, fabricated, calibrated, installed and flight-tested against actual auroral sky brightness distributions.[2] The instrument was later upgraded[1] by installation of a filter wheel, remote gain control switching, and decimal-digit time coding (hr, min, sec, millisec) on each frame. The time code signal also shows the gain control setting and indicates which of four wavelength-isolating filters is in the optical system. Fig 2 is a diagram of the camera's optical system and housing.

The video camera's function is (a) to provide a real-time, all-sky ($\pm \sim 80^{\circ}$ zenith angle) display of the auroral distribution, principally for use by the flight controller, and (b) to measure and record the spatial-temporal distribution of energy input in the neighborhood (within $\sim 10^{\circ}$ or $\sim$ 20 km horizontally) of the field of view of the aircraft's SWIR radiometer and photometers. (PhotoMetrics' Test Plan[5] for the measurement of infrared-visible correlations in aurorally-excited regions describes in detail application (b) of the video system.) The sky radiance distribution imaged by the wide-angle lens provides important information about the development of the auroral substorm, in particular about the location and movement of visible-arc systems.

To meet conflicting requirements for high angular resolution (as in application (b)) and wide-field coverage, the

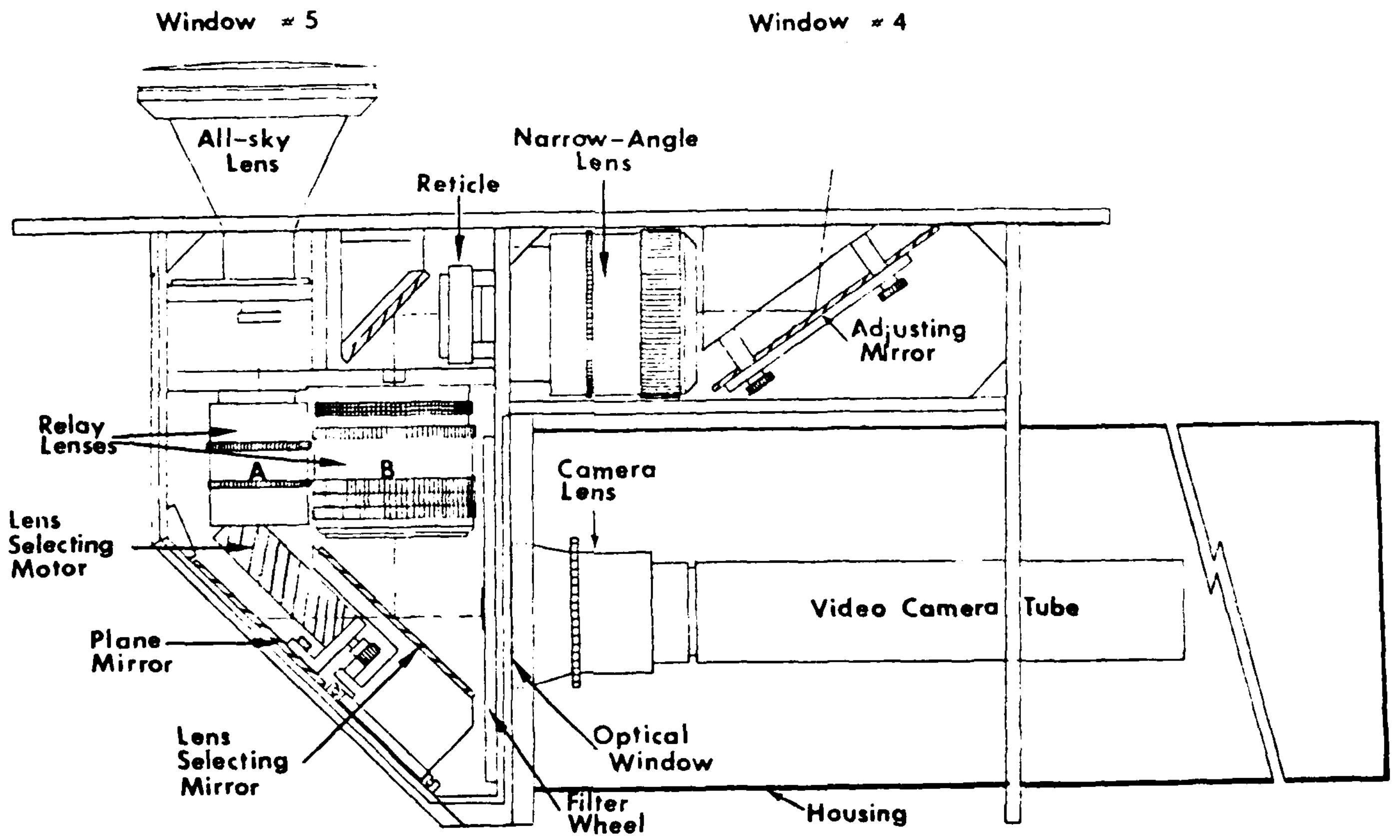

Figure 2. Diagram of low-light-level TV camera optics. The objective lenses are 1) a 3.45 mm fl f/1.5 Pacific Optical all-sky which provides a 165° circular field of view, and 2) a 35 mm fl f/1.4 Nikkor, which provides a 23.3° x 17.5° field of view when used with the camera tube. The camera lens is a 75 mm fl f/1.4. Relay lenses A&B are a 50 mm fl f/1.4 Cooke Ivotal, and an 85 mm fl f/1.8 Nikkor respectively. Field of view selection is remotely controlled from the console at Rack 14.

optical system was provided with two independent objective lenses (105° all-sky and $23^{\circ} \times 17\frac{1}{2}^{\circ}$) viewing through two separate aircraft windows (one a dome, the other flat). The camera itself is maintained in an airtight cylinder to meet USAF flight safety requirements for devices employing high electrical voltages. It was mounted sideways with a 45° mirror in the optical system (Fig 2) to maintain headroom in the aircraft. The camera tube is a vidicon of the Intensified Silicon Intensifier Target (ISIT) type, with S-20 cathode response. The effective aperture ratio of the lenses, considering all the reflection and absorption losses, is f/2.

An electronic control unit for the amplifier gain, stepping of the four-position filter wheel (which is placed at the telecentric stop of the optical system, where the beam is most nearly parallel), and other camera functions is located near the video monitor. The vidicon's motor-driven iris was kept fixed at maximum aperture, and the motor drive of its focus was disabled. This control system switches the mirror that allows light from one or the other of the two fore-optics lenses to pass through its relay lens to the video camera's internal (relay) lens (see Fig 2). A reticle was installed to improve location of auroral features in the narrow camera field. Engineering and wiring drawings and other Format AFSC Reg 80-33 documentation necessary for the camera's installation between Fuselage Stations 460 and 480 on the aircraft, were provided to USAF.

Filters installed in 1979[1] isolate the atomic oxygen 5577 Å $^1S - {}^1D$ and 6300 Å $^1D - {}^3P$ forbidden lines, and molecular nitrogen emissions below about 4700 Å. For the N_2 and N_2^+ features a Schott BG-12 dye filter is used, and for the O lines conventional interference filters with 20 and 23 Å full-width-to-half-maximum transmission. The fourth position in the wheel is left open, to achieve the full S-20 spectral response modified by absorption below ~3800 Å by the camera lenses.

The camera's spatial resolution at low scene radiances was tested against a low-brightness laboratory target at 5577 Å, with results such as are shown in Fig 3. Dynamic range at a fixed gain was measured with a step tablet to be 23:1. The camera was found to provide good imagery of weak aurora (as is quantified in Fig 3), and - equally important - to operate reliably under flight conditions. It also provided excellent imagery of ~1 kR 6300 Å airglow excited by the reactions of rocket exhaust gases with the ionospheric plasma in the launch of the HEAO-C satellite on 20 Sep 1979; this mission[4,9] succeeded in determining the extent and intensity of this and other ionospheric afterglows resulting from the trail release of water and hydrogen molecules from an Atlas-Centaur rocket launched from Cape Kennedy, FL.

Examples of images of aurora in four wavelength bands and of USAF bar charts illuminated by the low-brightness source, are given in Fig's 4 and 5.

FIELD CO-ALIGNER FOR AIRCRAFT OPTICAL INSTRUMENTS

Narrow-field (0.4° square) radiometers and photometers pointing ~15° from the zenith in a vertical plane through the aircraft's long axis were installed in the aircraft by AFGL to determine with high resolution the spatial-temporal correlation between infrared ("output")and visible ("input"-indicating) radiation from the particle-bombarded upper atmosphere. To

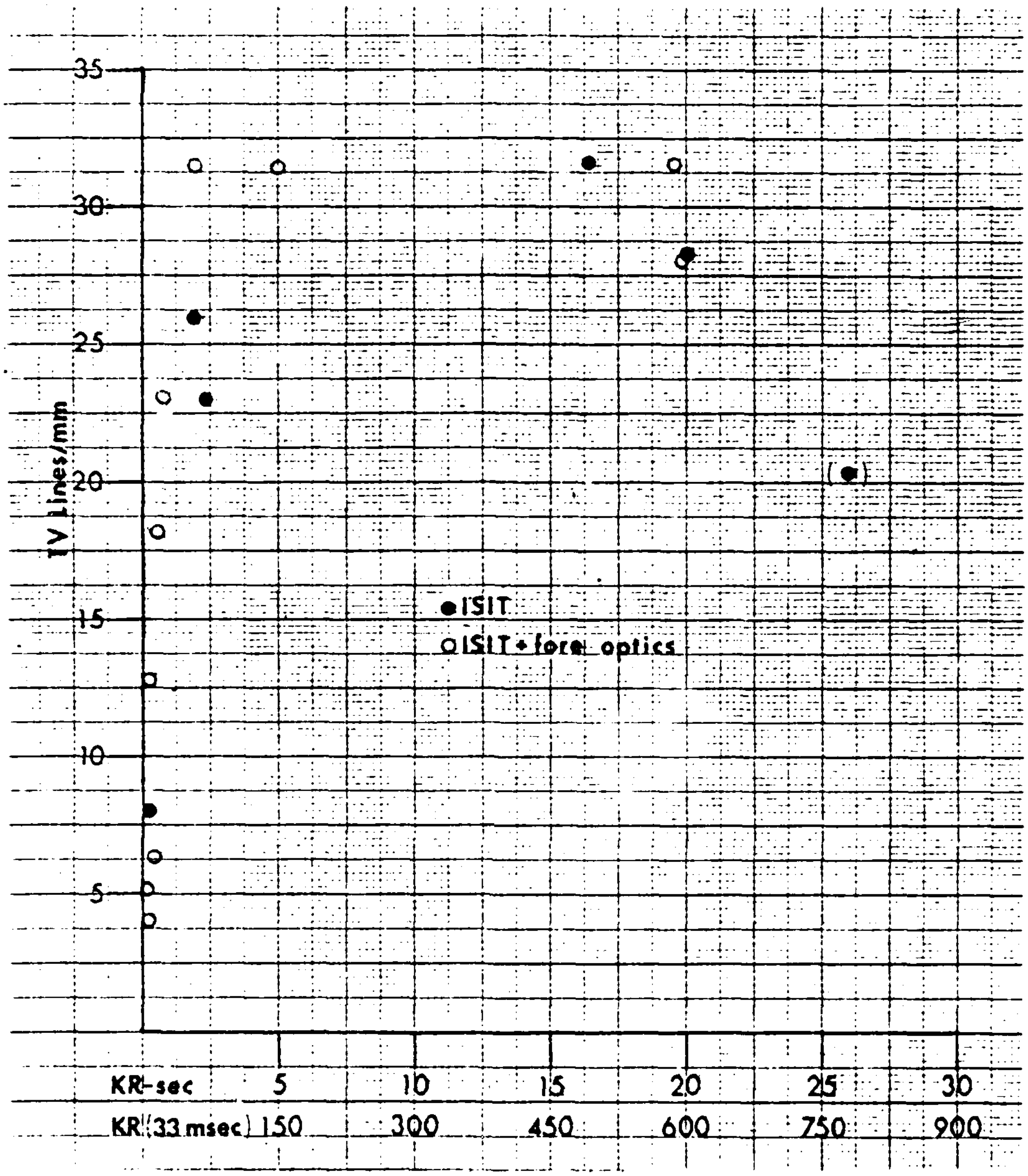

Figure 3. The limiting resolution in TV lines/mm at the center of the ISIT photocathode attainable as a function of scene radiance x time, and also a function of radiance for a single 33 msec TV frame. Solid points refer to the vidicon alone, open circles to vidicon with the narrow-field lens. The symbol kR refers to Kilo-rayleighs at 5577 Å.

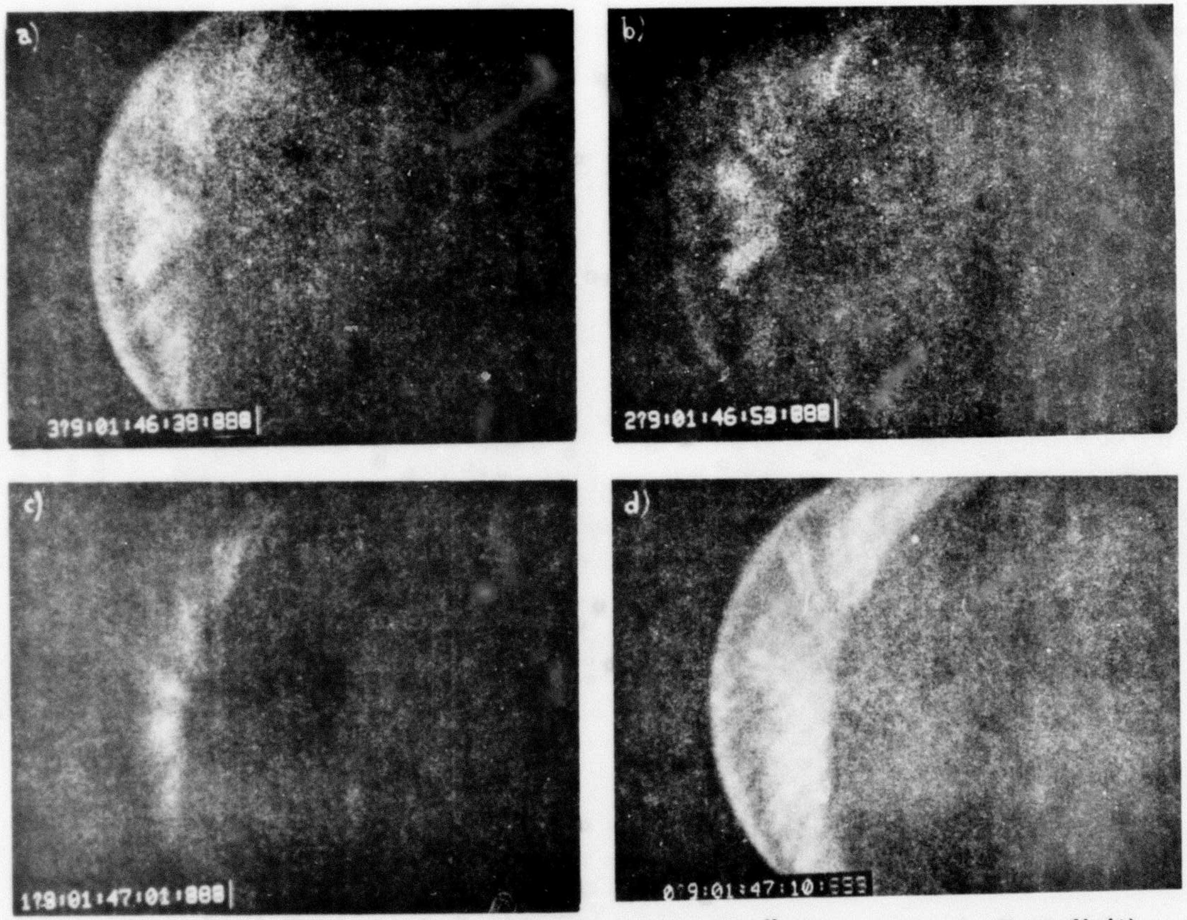

Figure 4. Auroral images recorded with a) the OI 5577 Å filter (code 3, first digit), b) the N_2 - N_2^+ short-wavelength bands filter (code 2), c) the OI 6300 Å filter (code 1), and d) no filter, S-20 spectral response of the cathode (code 0). These all-sky views were integrated for $\frac{1}{2}$ sec by photographing the TV monitor display with a $\frac{1}{2}$ sec exposure.

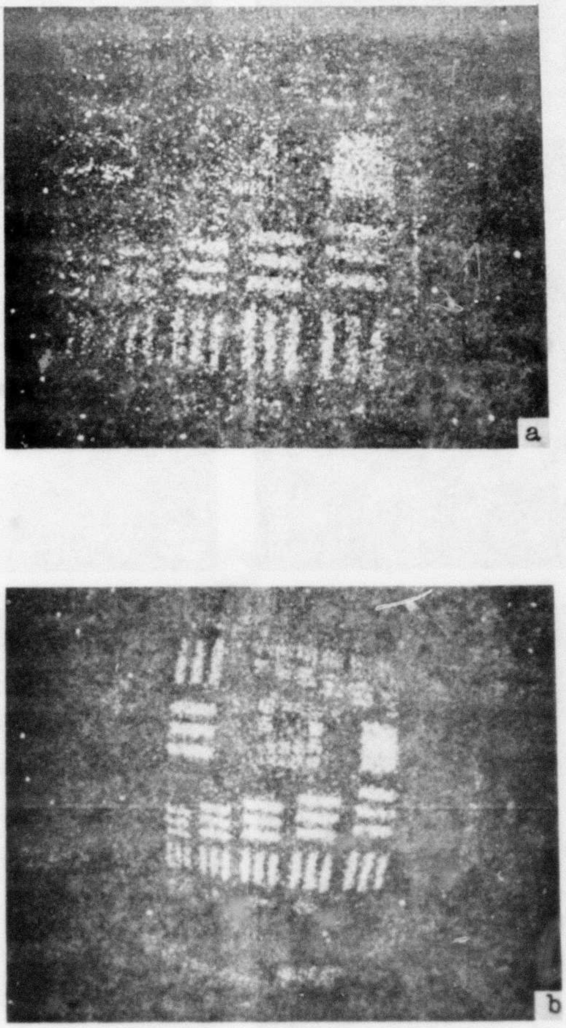

Figure 5. Images of Air Force bar targets illuminated by the low brightness source, as viewed through a) the narrow-field optical system, 0.1 kR-sec and b) the all-sky system, 1.0 kR-sec.

minimize systematic offset error, which might be misinterpreted as a real physical decorrelation between energy input and infrared radiation output, these instruments must point to the same region of sky to within a small fraction of their angular field. In addition the location of this field within the video camera's field must be known to allow the spatial distributions of input energy to be used in analyzing the aircraft data.

A total alignment error of less than 0.05°, or 3 arc min, was adopted as the design goal of an aligner for these aircraft instruments. The initial design study[1] indicated that an optical bench to be operated external to the aircraft, serving as the basis for an autocollimator-telescope, was the most effective design. Operation within the aircraft was impractical, as the cryocooled radiometer is sealed in an enclosure and the other instruments' fields are almost as inaccessible. The alignment system as finally constructed, which is intended for use with the aircraft parked on the ground, is shown in Fig 6.

The radiometer's optic axis is selected as the reference pointing direction. It should be noted that the absolute elevation and azimuth of this reference in flight is not known, due to the aircraft's unknown pitch angle, bending of the airframe and other factors; this, however, does not affect the auroral input-output measurements. Aluminum pads ($6\frac{1}{2}$ x $\frac{1}{4}$ x ~ 15 in, 16.5 x 0.6 x 38 cm) attached to the bench, which is a bonded honeycomb sandwich panel (Hexcel Corp., Dublin, CA) 150 cm long, define a rigid reference plane. Circular clearance holes $4\frac{1}{2}$ inches (11.5 cm) in diameter are cut into the bench at the positions of each of the three instruments; these allow a $3\frac{1}{2}$ inch (9.2 cm) diameter autocollimator (Questar) pointing through the aircraft windows either to illuminate a reference mirror installed in the radiometer, view the internally illuminated field stop of the

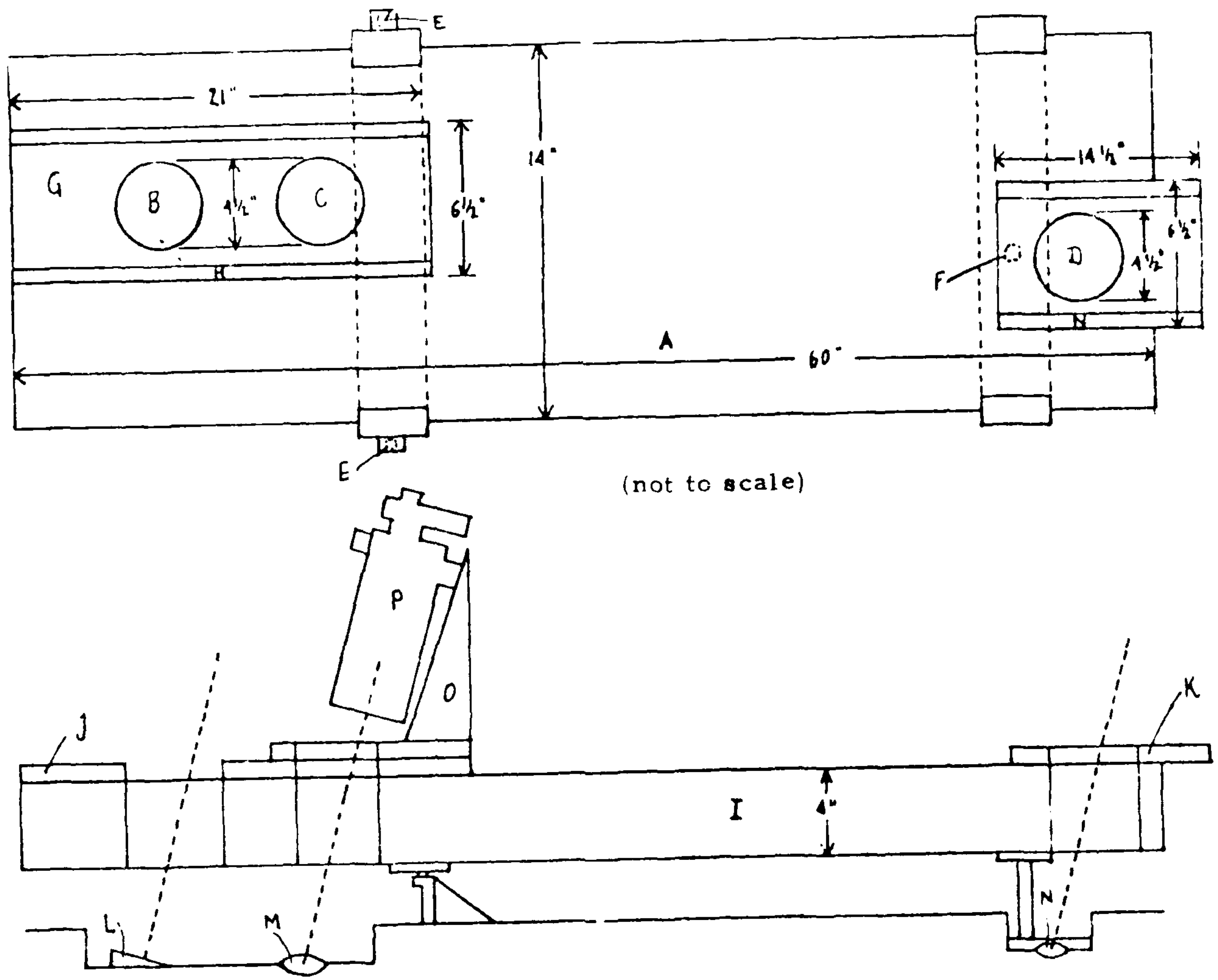

Figure 6. Schematic drawing of the aligner. A) Plan view of bonded honeycomb sandwich panel; B) radiometer opening; c) photometer opening; D) video camera opening; E) aft legs; F) forward leg; G) pad; H) orientation rails. I) Side view of panels; J) aft pad; K) forward pad; L) radiometer reference mirror; M) photometer lens; N) camera lens; O) sled; P) autocollimator.

photometer, or be imaged by the video camera. The optic axis of the narrow field of the video camera is moved by adjusting screws holding its 45° mirror (see Fig 2); the location of the focused image from the autocollimator is determined on the video monitor for identifying the direction parallel with the radiometer and photometer's optic axes. A three point suspension on the top of the aircraft, which makes use of one of the aerodynamic spoilers and one window edge, holds the optical bench in a stable position during the alignment procedure.

The autocollimator mounts on an aluminum "sled" that in turn is located on the bench by kinematic supports at the three instrument positions. Each of these supports is adjustable to allow the bench itself to be aligned in the laboratory, and checked prior to each alignment of the auroral instruments. This check is accomplished as follows: the autocollimator is swung from its nominal 15° inclination from the vertical to the horizontal, so as to point at a fixed flat mirror set about 1 meter from the aft end of the bench. When autocollimation is achieved at each of the instrument locations - by adjusting the kinematic supports as necessary - the bench is aligned in two-axes, pitch and yaw. The third axis is aligned by a precision surveyor's level mounted on the autocollimator sled.

The alignment procedure was performed before and during the auroral flight series in April-May and September 1979, in a hangar at Pease AFB. It requires two technicians working on top of the aircraft, in telephone communication with the instrument scientist adjusting the photometer's field from inside the aircraft. A drift in the photometer field after flight was identified, and corrected by its designers. Additionally, the autocollimator telescope turned out to be useful for adjusting the focus of the photometer's objective lens, which is set at infinity to image distant aurora on the field stop. The coalignment system was found capable of rapidly (< 3/4 hr from startup) and reproducibly setting instrument fields to well within the desired angular accuracy.

MODIFICATIONS OF PHOTOGRAPHIC AND VIDEO CAMERA INSTRUMENTATION

Several modifications of the mechanical mounting of the target cameras (System E-14) and silicon vidicon (E-209) were made to meet changing needs of the program for camera pointing directions and fields of view. In addition a photographic camera was boresighted through a coherent fiber optic bundle to the trainable Type V/101 interferometer at Fuselage Station 1330 for nadir-viewing, and a video camera was installed at that station; and a periscoped trackable 16 mm format photographic (Type 1VN) camera was located at Station 630 for aft viewing of targets. The periscope works in conjunction with a rotatable "eyeball" aircraft window designed by OPR.[6] Film exposure in the photographic cameras was automatically adjusted with a CdS cell-based brightness sensor having a 15° field of view.

Engineering documentation for these modifications was provided. Lenses and long-pass filters (to improve contrast of targets against the "blue" scene background) were procured and installed, and liaison maintained with AFGL staff to ensure accurate, effective boresighting.

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